Prediction of Hydrodynamics for Unidirectional Flow

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LONG-TERM GOALS

Our long term goal is to gain a thorough understanding of the flows in the regions of the ocean ranging from the inner shelf through the surf zone to the upper reaches of rivers. We aim to develop integrated observation and modeling systems that are able to observe and predict them.

OBJECTIVES

Over the next two years our aim is to transition from the study of nearshore currents to the study of river current. Our approach is to apply methods used in nearshore circulation (in particular longshore current predictions) to the prediction of flow in riverine environments. Specific objectives are:

1. Complete work on publications related to circulation in the nearshore zone currently under preparation.

2. Carry out a focused study for the application of variational data assimilation (DA) methods to steady state river problems using simple dynamical models for the flow field. The work will be geared towards obtaining estimates of upstream conditions, frictional parameters and channel topography given observations of stream velocities at several locations. This work will be carried out in two phases

    - Assess the utility of a shelf/surf zone circulation model (e.g. ROMS) in determining the 2D flow field in a river setting.

    - Implement variational DA into a simple 1D river flow model (assuming a straight channel and no cross-stream flow).

    - Use a simple 2DH formulation for flow in a meandering stream and apply variational DA methodology in this more realistic 2D setting.

APPROACH

The work proposed herein involves a transition from studying the dynamics of nearshore flows to the study of riverine environments. First we finalize two publications. The first involves a look at the response of the wave-induced circulation field to forcing by a sequence of wave groups of varying strengths and scales. There has been some disagreement in previous literature on this subject, and our

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results show that the circulation field responds in a forced and coupled manner to the wave group forcing. The second manuscript involves simulations of the NCEX field experiment during the entire month of October 2003. Our results show the controls on rip current generation, location, persistence and decay and involve comparisons to video and in-situ observations.

The remainder of the work will involve a shift to river environments. We will focus our attention on steady state conditions and time scales over which the channel topography does not change appreciably (O(hours)). The work will be carried out with an eye towards inverting the dependency of the flow on channel geometry, upstream boundary conditions, and frictional characteristics. There are many parallels between river flows in a channel and longshore currents in the nearshore (especially in situations where the beach is barred and strong alongshore pressure gradients exist), so lessons we have learned during longshore current simulations should transfer to this new area. The scope of this work will necessarily be quite focused so that the study can be completed (to publication stage) within the two-year time-frame of the project. Our focus is on establishing whether or not DA methods are useful for the problem of flow through a realistic river channel.

Finally, we retain a small involvement in nearshore research over these two years.Our approach is to simulate the wave and circulation fields at two different field sites (Duck, NC and NCEX near La Jolla, CA) primarily during periods of concentrated field experiments using several representative wave and circulation models. The available data ranges from in-situ observations, to remote sensing observations of surf zone width, wave dissipation, and surface current velocities. Our goal is to carry out comparisons for a statistically significant number of runs. This type of model scrutiny is rare in the literature; yet studies that exist (e.g. Ruessink *et al*., 2001) can draw significant conclusions about the applicability and robustness of a modeling system. By simulating a statistically significant number of data runs we will quantify model skill and define confidence limits on our predictions. Further, estimates of model sensitivities will lead to a better understanding about the required accuracy of model input and boundary fields (such as measured bathymetry). Finally, estimates of the magnitude and spatial correlation of model errors can be assembled. Such estimates are a crucial step towards employing data assimilation methods that will lead to integrated observation/prediction systems.

WORK COMPLETED

We have examined in detail the temporal response of these vortices to a sequence of successive wave groups of varying magnitude. In particular, we are interested in the theoretical relationships between wave forcing, bottom friction and flow accelerations. A phase-averaged wave propagation and circulation model that includes wave-forcing and bottom friction is used to analyze the vorticity response to idealized and random sequences of incident wave groups.

RESULTS

We find that existing vortices are directly affected by successive wave groups which can either reinforce the vortex or actively slow it down, even when the subsequent wave group is of smaller magnitude than the group that originally forced the vortex. As expected, wave groups that do not break on the nearshore bar do not ffect the vortex dynamics. A vortex tracking method is employed to follow vortices through space and time allowing a potential vorticity balance to be computed for an individual vortex throughout its lifespan. The integrated potential vorticity balance for each case shows a dominant balance between the curl of the wave forcing and the acceleration of potential vorticity.

While the vortex acceleration oscillates at the wave group time scale (O(2min)), a vortex can remain in the domain for O(10 min) after it is generated. We find that the long-term vortex lifespan is not indicative of a slow frictional decay of an initially strong vortex, rather it is correlated with low-frequency signals in the incident wave group forcing.

Analyzing results from the circulation model, we defined a rip current as any cross-shore velocity exceeding 10 cm/s exiting the surf zone. The outer edge of the surf zone was determined as the location of initial onset of breaking in the wave model. This analysis was performed for each hour of the 23-day simulation. Using this long time series we separated the results into northern sea/swell conditions and southern swell conditions. For northern sea/swell conditions rip current velocities were linearly related to variations in wave energy (r^2=0.75) during conditions with significant wave height larger than 0.75m. Consequently we refer to these conditions as high-energy waves. For all northern wave simulations rip currents developed for all recorded wave heights. However, we found that the alongshore location of the rip currents depended on the peak period. In particular, northern seas generated rip currents near Blacks beach and further north, whereas northerns swell generated rip currents throughout the domain including south of the Scripss pier. For southern swell conditions few rips, if any, were predicted. Southerns swell in general was not as energetic as northern waves; however, sensitivity analysis using larger soutern waves indicated that rips would still not be predicted. Figure 1 demonstrates the frequency and strength of observed rip currents at 3 of the 8 locations we tracked. Figure 2 and Figure 3 show the correspondence between of predicted currents and Argus video images as well as in-situ current observations.

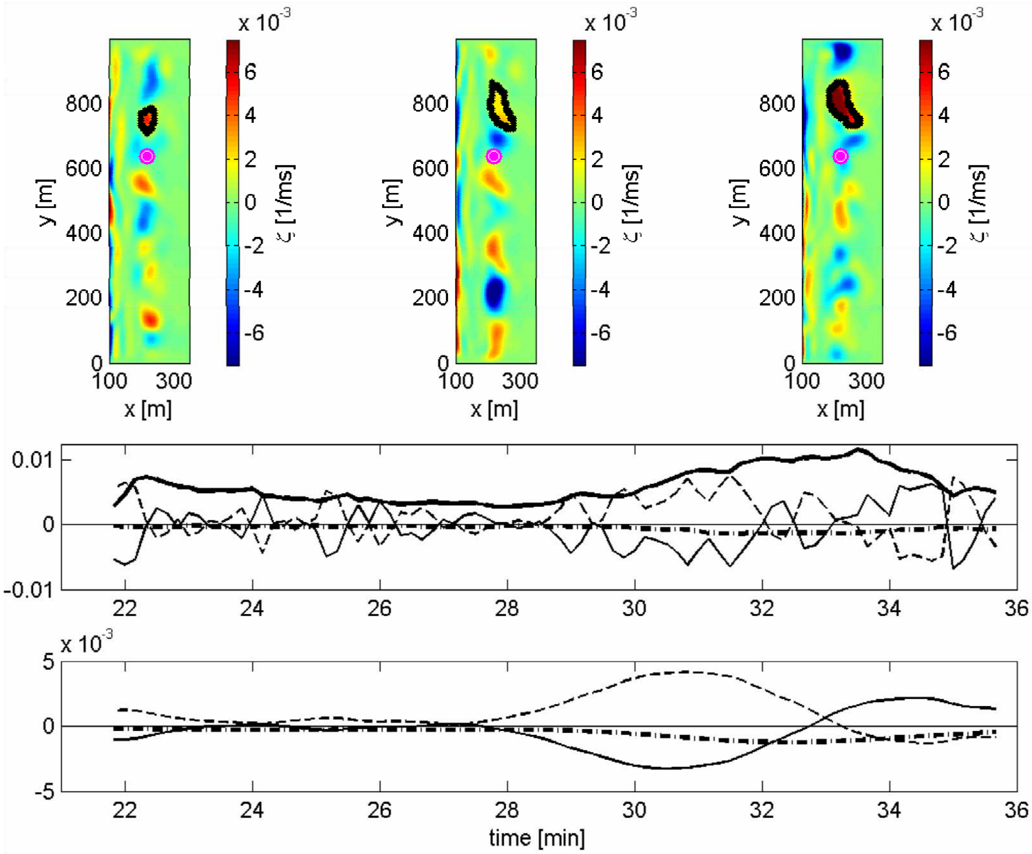

Figure 1: Random Wave Group Sequence: The top three panels show snapshots of the vortex position at t= 23.2, 28.2, and 33.2 minutes from left to right, respectively. The potential vorticity balance (middle) for a vortex tracked through its lifespan is also shown; potential vorticity extremum (thick solid line), total acceleration in potential vorticity (thin solid line), curl of wave forcing (thin dashed line), curl of bottom friction (thick dash-dot line). The bottom subplot gives the low-passed (T >200s) potential vorticity balance.

IMPACT/APPLICATIONS

As part of this study we have so far found that wave groups impinging upon the shore force vortex pairs that can survive for up to 15 minutes as they accelerate or decelerate due to subsequent groups. Previous studies had shown (Reniers et al, JGR 2004) that these vortices can be important in the generation of rip channels but had not explained the mechanism underlying their long term survival.

PUBLICATIONS

Long, J.W., and H.T. Özkan-Haller, Temporal response of wave group forced vortices, Journal of Geophysical Research, in review, 2007.